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EXPERIMENTAL ANALYSIS OF ENERGY PARAMETERS DRIVE MECHANISMS HYDRAULIC EXCAVATOR

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Abstract

In this paper a general mathematical model and a program is developed for analysis of energy parameters of driving mechanisms hydraulic excavator with backhoe manipulator, according to the measured quantity of state of excavator operating in real exploitation conditions.

***Key words**: hydraulic excavator, energy parameters*

1 INTRODUCTION

Hydraulic excavators belong to the group of mobile machines whose primary function is cyclic (intermittent) transport of a variety materials in a certain workspace. The most common are in technological chain with other mobile machines in the execution of extensive earthworks in building a large infrastructure, (roads, settlements, dams). In general, regardless of size, the cyclic function excavator consists of various manipulative tasks, which comprise the following operations: loading materials, transfer materials from the level of loading to the level and the position of unloading, the unloading materials and selection of the new plane and the position of loading [1].

Energy analysis parameters (drive torque and power) of the drive mechanisms of manipulator and slewing platform of excavator aims to:

- determine the character of change required drive torque and power of the members of manipulator and slewing platform of excavator,
- evaluate the proportion of energy parameters of the mechanism of manipulator and slewing platform in relation to the total energy balance of excavator in the performance manipulation tasks. Energy analysis was performed by analysis of the experimental procedure which is performed on the basis of measured quantity of state while excavator operating in real exploitation conditions.

2 MATHEMATICAL MODEL

In this paper a general mathematical model and a program is developed for analysis of energy parameters of driving mechanisms hydraulic excavator with backhoe manipulator, according to the measured quantity of state of excavator operating in real exploitation conditions.

Mathematical model is developed for general configuration of the excavator kinematic chain composed of: the support and movement mechanism L_1 (*Fig.1*), the slewing platform L_2 and the three-plane load manipulators with: boom L_3, stick L_4 backhoe bucket L_5. Kinematic pair support and movement mechanism and slewing platform connected rotary joint of the fifth class in the form of a axial bearing. The drive mechanism of the slewing platform makes excavator hydraulic motor and gearbox whose gear on the output shaft is coupled to the toothed wreath of axial bearing. Driving mechanisms of boom, stick and bucket manipulator for actuators have two way acting hydraulic cylinder c_3, c_4, c_5. Member of the kinematic chain excavator L_i, determined in its local coordinate system $O_i x_i y_i z_i$ with set size:

$$L_i = \{\hat{e}_i, \hat{s}_i, \hat{t}_i, m_i\} \qquad (1)$$

where: $\hat{e}_i$ - the unit vector of joint O_i axis which connects member L_i to the previous member L_{i-1}, $\hat{s}_i$ - the vector of the position of joint O_{i+1} center which is used to connect the chain member L_i to the next member L_{i+1}, $\hat{t}_i$ - the vector of the position of the member mass center, m_i - the member mass.

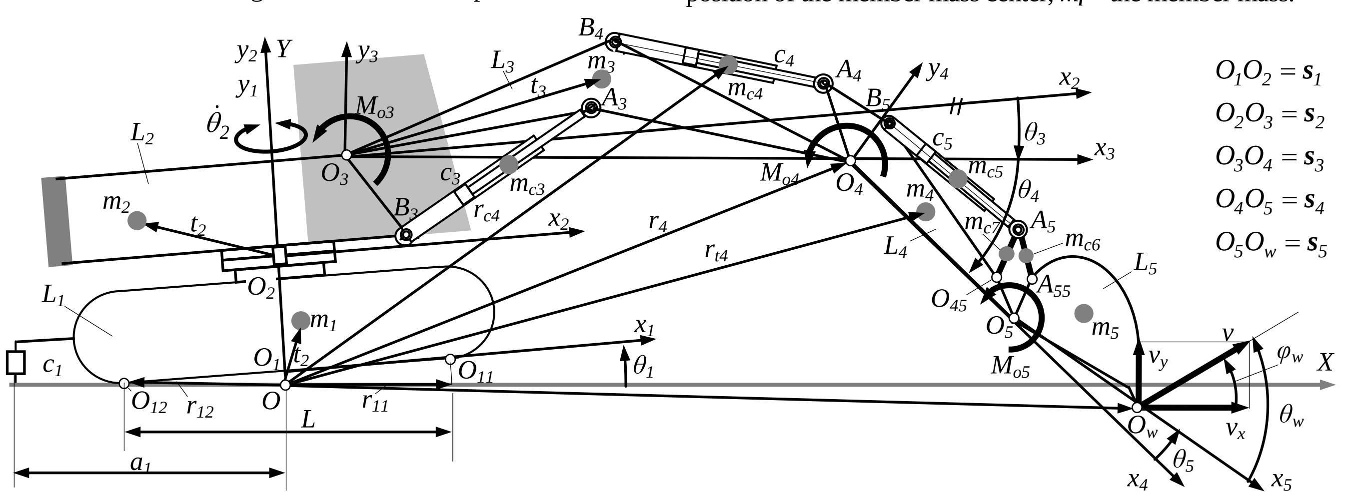

***Fig.** Mathematical model for experimental analysis of energy parameters drive mechanisms of hydraulic excavator*

Driving mechanisms excavator are defined with set of size:

$$C_i = \{d_{i1}, d_{i2}, \boldsymbol{a}_i, \boldsymbol{b}_i, m_{ci}, n_{ci}\} \quad (2)$$

where: d_{i1}, d_{i2} - the transformation parameters of the actuator driving mechanisms (d_{21} - specific flow of the hydraulic motor platform drive, d_{i1}, d_{i2} - the diameter of the piston and the piston rod hydrocylinder driving mechanisms of the manipulator ($i=3,4,5$), $\boldsymbol{a}_i$, $\boldsymbol{b}_i$ - parameters of the transfer functions of the drive mechanism of excavators, m_{ci}, n_{ci} - mass and the number of actuator driving mechanisms excavator). A set of measured values (Table 1) of excavator operating in the exploitation conditions are included: lifting support and movement mechanism, platform rotation angle, hydrocylinder motiomns and pressure in the lines of the actuator driving mechanisms.

Generalized coordinates mathematical model kinematic chain of excavator represent angles θ_i of relative position of a member of L_i i in relation to the previous member of the L_{i-1} due to the rotation about the joint axis O_i.

Liffing angle of support and movement mechanism θ_1 is determined depending on the measured relative vertical displacement c_1 support and movement member L_1 in relation to the substrate reliance:

$$\theta_1 = \begin{cases} -arctg\dfrac{2 \cdot c_1}{L + 2 \cdot a_1} & \forall c_1 \geq 0 \\ -arctg\dfrac{2 \cdot c_1}{2 \cdot a_1 - L} & \forall c_1 \leq 0 \end{cases} \quad (3)$$

where: c_1 - the size of lifting support and movement mechanism, a_1 - coordinate position encoder lifting support and movement mechanism, L - length footprint caterpillars. Depending on the measured electric quantities c_i, c_i ($i=2,...,5$) using transfer functions of driving mechanisms, determine the other generalized coordinates θ_i, the basis of which is determined, by differencing, the angular velocity $\dot{\theta}_i$ of the members of the kinematic chain of excavator [2]:

$$\dot{\theta}_i = \frac{\theta_{i(t+\Delta t)} - \theta_{i(t-\Delta t)}}{2\Delta t} \quad (4)$$

where: $\theta_{i(t)}$ - generalized coordinates at time t of cycle, $\theta_{i(t+\Delta t)}$, $\theta_{i(t-\Delta t)}$ - generalized coordinates in moment of time that is for one time interval Δt greater or less than the time t, Δt - the time interval between two successive measured quantities.

The driving torque of the mechanism of the slewing platform and mechanisms of manipulator are defined with equation:

$$M_{pi} = \begin{cases} sign(\dot{\theta}_i) \cdot i_{ci}^M \cdot n_{ci} \dfrac{d_{21}}{2\pi}(p_{i1} - p_{i2}) \\ \forall\ i = 3,4,5;\ \dot{\theta}_3 > 0,\ \dot{\theta}_4 < 0,\ \dot{\theta}_5 < 0 \\ sign(\dot{\theta}_i) \cdot i_{ci}^M \cdot n_{ci} \dfrac{(d_{i1}^2 - d_{i2}^2)\pi}{4}(p_{i2} - p_{i1}) \\ \forall\ i = 3,4,5;\ \dot{\theta}_3 < 0,\ \dot{\theta}_4 > 0,\ \dot{\theta}_5 > 0 \end{cases} \quad (5)$$

where: i_{c2}^M - the transfer function of the drive mechanism of the slewing platform, i_{ci}^M - the transfer function of the drive mechanism of the manipulator ($i=3,4,5$).

Power of excavator drive mechanism is determined by the equation:

$$N_i = M_{pi} \cdot \dot{\theta}_i \ , i = 2,\ldots,5 \quad (6)$$

3 EXAMPLE OF ANALYSIS

According to defined mathematical model, a program was developed on the basis of which carried a detailed experimental analysis energy parameters of drive mechanism hydraulic crawler, mass of *17000 kg* and a backhoe bucket volume $0{,}6m^3$. The analysis was performed on the basis of the measured values of excavator operating in exploitation conditions for the manipulative task - digging a channel from supporting surface of the excavator to the excavation depth of 1.3 m, the channel width is equal to the width of the buckets [3]. Such manipulative task corresponds, in practice, the most applied technology of excavator operating with backhoe manipulator.

Part of the results of analysis are given in diagram form of changes of angular velocity the members of the kinematic chain (Fig.1a), drive torque M_{pi} (Fig.1b) and power N_i (Fig.1c) of the drive mechanism of the slewing platform ($i = 2$) and drive mechanism the manipulator excavator ($i = 3,4,5$) duration allocated manipulativ task.

Changes angular velocities (Fig. 2a) show that the operation digging, which lasted until $t = 6{,}7s$, held by running stick and intermittent running the bucket wherein the boom was standing. In operation, material transfer, first there was a simultaneous lifting of the boom and stick, and then turning to the platform by the end of the operation $t = 13s$.

Table1 Measured quantities of the state of the kinematic chain and excavator drive mechanisms [3]

Name of the measured quantity	Symbol	Dimension
Lifting of the support and movement mechanism	c_1	*m*
Platform rotation angle	c_2	^{o}
Boom hydraulic cylinder motion	c_3	*m*
Stick hydraulic cylinder motion	c_4	*m*
Bucket hydraulic cylinder motion	c_5	*m*
Pressure in one duct of the hyd. motor for platform rotation drive	p_{21}	*MPa*
Pressure in other duct of the hyd. motor for platform rotation drive	p_{22}	*MPa*
Pressure in the boom hydraulic cylinder on the piston side	p_{31}	*MPa*
Pressure in the boom hydraulic cylinder on the connecting rod side	p_{32}	*MPa*
Pressure in the stick hydraulic cylinder on the piston side	p_{41}	*MPa*
Pressure in the stick hydraulic cylinder on the connecting rod side	p_{42}	*MPa*
Pressure in the bucket hydraulic cylinder on the piston side	p_{51}	*MPa*
Pressure in the bucket hyd. cylinder on the connecting rod side	p_{52}	*MPa*

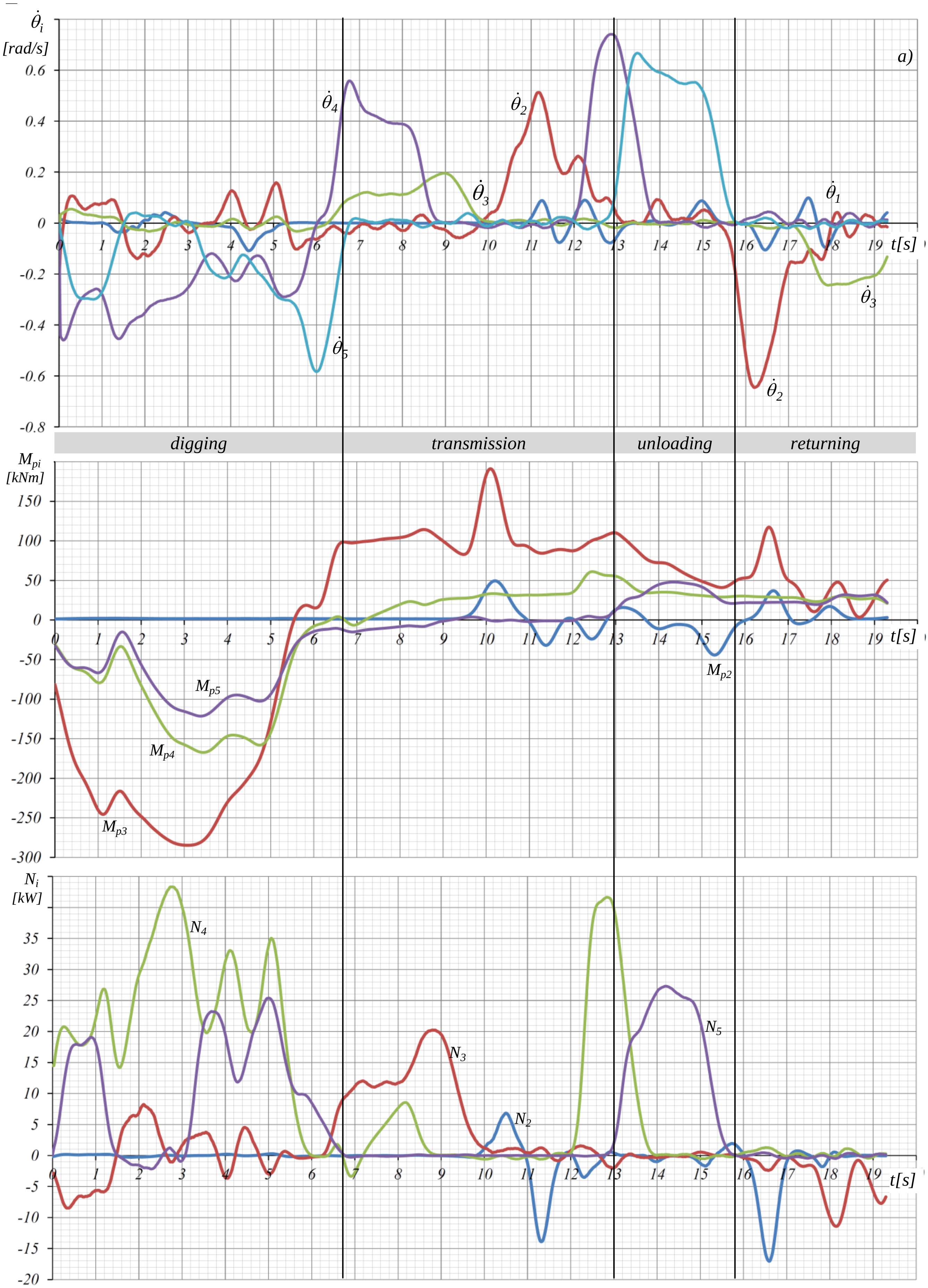

***Fig. 1** Experimental analysis of energy parameters: a) angular velocity of the slewing platform $\dot{\theta}_2$, boom $\dot{\theta}_3$, stick $\dot{\theta}_4$ and bucket $\dot{\theta}_5$ b) driving torque of the mechanism of slewing platform M_{p2} and mechanisms of manipulator M_{p3}, M_{p4}, M_{p5} c) power of excavator drive mechanism N_2, N_3, N_4, N_5*

Unloading operations began simultaneous running stick and bucket, and ended up, $t=15,8\ s$, with just opening the bucket. Return operation to a new plane of digging continued until $t= 19,2s$, and was achieved by rotating platforms and descending boom.
Character changes of angular velocity the members of the kinematic chain, during manipulative task, occurs most frequently in the form of a triangle or trapezoid shape with expressed phases of accelerated and decelerated motion. The highest values of angular velocity have srick and a platform for the operation of transmission and bucket in the unloading operation.
Change of energy parameters indicate that the torques M_{p2} (Fig 1b) and power N_{p2} (Fig 1c) of the drive mechanism the rotating platform, during an operation of digging are negligible small. The reason for this small energy values, is balanced side resistances of digging that act normal to external sites of buckets and small dynamic impact due to the slow movements of members of the kinematic chain excavator. In digging operation, the drive torque of mechanism boom M_{p3}, stick M_{p4} and bucket M_{p5} have the highest value because occurrences highest load due to impact resistance digging. In the same operation there are highest values of required drive power, particularly in stick mechanism stick N_{p4} and buckets N_{p5}. Drive torque and power rotation a mechanism platform during manipulative task in operation of transmission, unloading and return to a new level digging, have little values in relation to the mechanisms of the manipulator.
The reason for this small energy values are low torque load drive slewing platform of inertial forces and moments of inertia of members the kinematic chain manipulator and the loaded material. Wherein the kinematic chain excavator has an open configuration, and on driving torque and the power a mechanism of the slewing platform have no influence the gravitational force and the components resistance digging.
In the phases of stopping rotation the platform, in operations the transmission material and returning to a new digging level, power drive of slewing platform has a negative values that is lost when braking or recuperating accumulate (in modern hybrid drive systems excavator) and then, if necessary, returns to the operating system use in other operations manipulative task excavator.
In transmission operation the largest energy parameters have a drive mechanism boom, less values drive mechanism of platform, and extreme value of the drive mechanism stick due to lifting bucket on required unloading height.
The highest value of the energy parameter has bucket drive mechanism when occurs opening bucket during an operation for unloading material. It is characteristic that at the end of unloading operations came the beginning of rotation the platform to the new level digging, and during the whole of return operations platform to a new level digging, platform had a stop movement character.Then occurred the negative values the power drive mechanism platform. In the same operation, descending boom, due to the action of gravitational forces affects the negative values of power of the drive mechanism boom, which can also by recuperating can be accumulated and returned to the use of the drive system in the other operations. Conducted energy analyze of excavator, shows significant changes parameters of the drive mechanism during operation of the task manipualcionog excavator.

4 CONCLUSION

This paper presents the analyze energy of driving mechanisms of the hydraulic excavator with a shovel manipulator. Carried out by the method of experimental analysis on the basis of the measured values status excavator working in exploitation conditions.
Changes in energy parameters show that the drive torque and required power, the drive mechanism of the slewing platform during manipulative task, relatively small in relation to the drive torque and required power of boom, stick and bucket drive mechanism of manipulators. The highest values of energy parameters occur in the operation digging, particularly in driving mechanisms of manipulators. Conducted analysis show that in phases, when stopping a simplified operations, occur negative values of the driving power, which advanced hydraulic excavator with hybrid drive systems recuperating. Results of the analysis can be used in the optimization of driving mechanisms of the excavator.

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